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RESEARCH ARTICLE

Analysis of duet vocalizations in *Myiothlypis leucoblephara* (Aves, Parulidae)

Análise sonora de dueto de *Myiothlypis leucoblephara* (Aves, Parulidae)

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Abstract

Bird vocalizations might be used for specific recognition, territorial defense, and reproduction. Bioacoustic studies aim to understand the production, propagation and reception of acoustic signals, and they are an important component of research on animal behavior and evolution. In this study we analyzed the sound structure of duet vocalizations in pairs of *Myiothlypis leucoblephara* and evaluated whether the vocal variables differ among pairs and if there are differences in temporal characteristics and frequency of duets between pairs in forest edges vs. forest interior. Vocalizations were recorded from 17 bird pairs in three remnants of Atlantic Forest in southern Brazil. Six of the bird pairs were situated at the edge of the forest remnant, and 11 were in the interior of the remnant. The duets of different pairs between forest areas showed descriptive differences in the frequency, number of notes per call, and time between issuance of calls, with the main distinguishing feature being a change in frequency of a few notes in the second part of the musical phrase. The minimum frequency of vocalization was reduced at the private area than in the other two remnants ($p < 0.05$). The duets of birds in the forest edge and forest interior did not significantly differ in minimum or maximum frequency of phrases ($p > 0.05$), phrase duration ($p > 0.05$) or number of notes per phrase ($p > 0.05$). *Myiothlypis leucoblephara* did not show a specific pattern with respect to issue of phrases in duets, but instead showed five different patterns, which were variable among pairs. There was a sharp decline or alternation in frequency between notes in the second part of the musical phrase for recognition among pairs. Variation in vocalization among *M. leucoblephara* duets may play a role in pair recognition.

Resumo
A vocalização em aves pode ser usada para reconhecimento de espécies, defesa territorial e reprodução. Estudos bioacústicos têm o objetivo de entender a produção, propagação e recepção de sinais acústicos, sendo importantes em pesquisas de comportamento animal e evolução. No presente estudo, analisamos a estrutura sonora da vocalização em duetos de *Myiothlypis leucoblephara* e avaliamos se as variáveis vocais diferem entre os pares e se existem diferenças nas características temporais e na frequência de duetos entre pares nas bordas da floresta versus interior da floresta. Vocalizações foram registradas de 17 pares de aves em três remanescentes florestais no oeste de Santa Catarina, no sul do Brasil. Seis dos pares de aves estavam situados na borda do remanescente da floresta e 11 no interior. Utilizamos os testes de Kruskal-Wallis e Mann-Whitney U. Os duetos de pares diferentes analisados em todos os remanescentes apresentaram diferenças descritivas na frequência, número de notas por frase e tempo na emissão de notas, sendo que a principal característica é a mudança de frequência de algumas notas da segunda parte da frase. A frequência mínima das vocalizações foi menor na área da Aurora ($p<0,05$). Os duetos comparados entre borda e interior de mata não tiveram diferenças significativas de frequência mínima das frases ($p > 0,05$), frequência máxima ($p > 0,05$), tempo de duração das frases ($p > 0,05$) e número de notas por frase ($p > 0,05$). A espécie não apresentou um padrão específico na emissão das frases nos duetos, apresentando cinco padrões diferentes e estes são variáveis entre os pares. *Myiothlypis leucoblephara* apresenta características de diminuição brusca ou alternância de frequência entre notas da segunda parte da frase. Estas variações na vocalização em diferentes duetos da espécie apontam as características de reconhecimento entre os pares.

Keywords
Atlantic forest, bioacoustics, vocal behavior

Palavras-chave
comportamento vocal, bioacústica, Floresta Atlântica

Introduction

Vocal communication is the exchange of information made between sender and receiver individuals (Vielliard 2000) and is an important way of information exchange between birds (Sick 1997; Silva and Vielliard 2011). Bioacoustic studies examine animal vocal displays (Sigrist 2006) and aim to understand the production, propagation and reception of acoustic signals. Such studies are an important component of research into animal behavior and evolution (Salvador 2008).

Bird vocalizations are mainly important for territory defense, attraction of the opposite sex (Vielliard 1987; Sick 1997; Storer et al. 2002; Sigrist 2006; Pijanowski et al. 2011; Pereira 2011) and species recognition (Vielliard 1987; Silva 1995), and play a key role in the evolution and survival of species and ecosystem function (Vielliard 1987). Bird acoustic signals are essential for communication (Vielliard 2000), and vocalization height and amplitude variables can be related to home range location and spatial distance between individuals (Storer et al. 2002).

The acoustical code allows for the recognition of individuals of the species. Individual recognition can be achieved if an individual emits an acoustic signal distinct from the signal of other individuals, even though the specific recognition code might

still be retained (Vielliard 2004). It is well understood that birds might recognize each other through vocalization, but little is known about the specific features of the vocalizations that facilitate individual recognition in territorial birds (Aubin et al. 2004).

Some birds may vocalize in duets, which occurs when two conspecific individuals vocalize in combination with each other either synchronously or alternately, usually in response to reproductive interaction or territory defense (Langmore 1998). The duet has the function of cooperative protection of territory, as well as territorial care in response to reproduction and paternal custody during the fertility of the females (Topp and Mennill 2008).

Myiothlypis leucoblephara (Vieillot, 1817), commonly known as the white-browed-warbler, is a common and abundant bird in the Atlantic forest (Aubin et al. 2004). This species is typical of underbrush and montane forests (Sigrist 2006) and maintains intense vocal activity throughout the year (Silva 1991). Its vocalization is strong and melodious, starts quickly and goes on a clear and descending scale (Develey 2004), consisting of a succession of very similar notes that slowly decrease in frequency (Aubin et al. 2004). Aubin et al. (2004) produced the only study on *M. leucoblephara* vocalization, in which individual vocalizations were evaluated. No studies, to our knowledge, have examined duet vocalizations in this species.

In this study we analyze duet vocalizations' structure in *M. leucoblephara*, seeking to determine song characteristics involved in individual recognition between pairs. We also compare the physical variables of song units between duetting birds occupying two different environments: forest edges and interior. We work with the hypothesis that there are duets with different characteristics, which may indicate the recognition between the individuals of a pair.

We expected to record higher and lower frequencies in Hz and a larger number of notes per phrase in the edge environment, because this site has more noise interference when compared to the interior of the forest.

Material and methods

Study area

We selected three forest remnants: one in a private area (PA), named Central Cooperative Area of West Santa Catarina (27°8'15.24"S, 52°42'46.48"W), and the other two remnants in a conservation unit, the National Forest of Chapeco (1.590,60 hectares, divided into 3 glebas), namely NF-1 (26°55'00"S, 52°55'00"W) and NF-2 (27°15'00"S, 52°35'00"W) (Fig. 1). The three remnants are located in the western region of the state of Santa Catarina, southern Brazil. The NF-1 lies in the Guatambu municipality and has an area of 1287.54 ha; the NF-2 lies in the city of Chapecó and has an area of 303.60 ha (ICMBio 2013). The PA is located in Chapecó between NF-1 and NF-2 and has a total area of 270 ha. All sites are within the Atlantic Forest, in transition between Seasonal Deciduous Forest and Mixed Ombrophilous Forest, and the climate is subtropical (ICMBio 2013). The remnants named NF-1 and NF-2

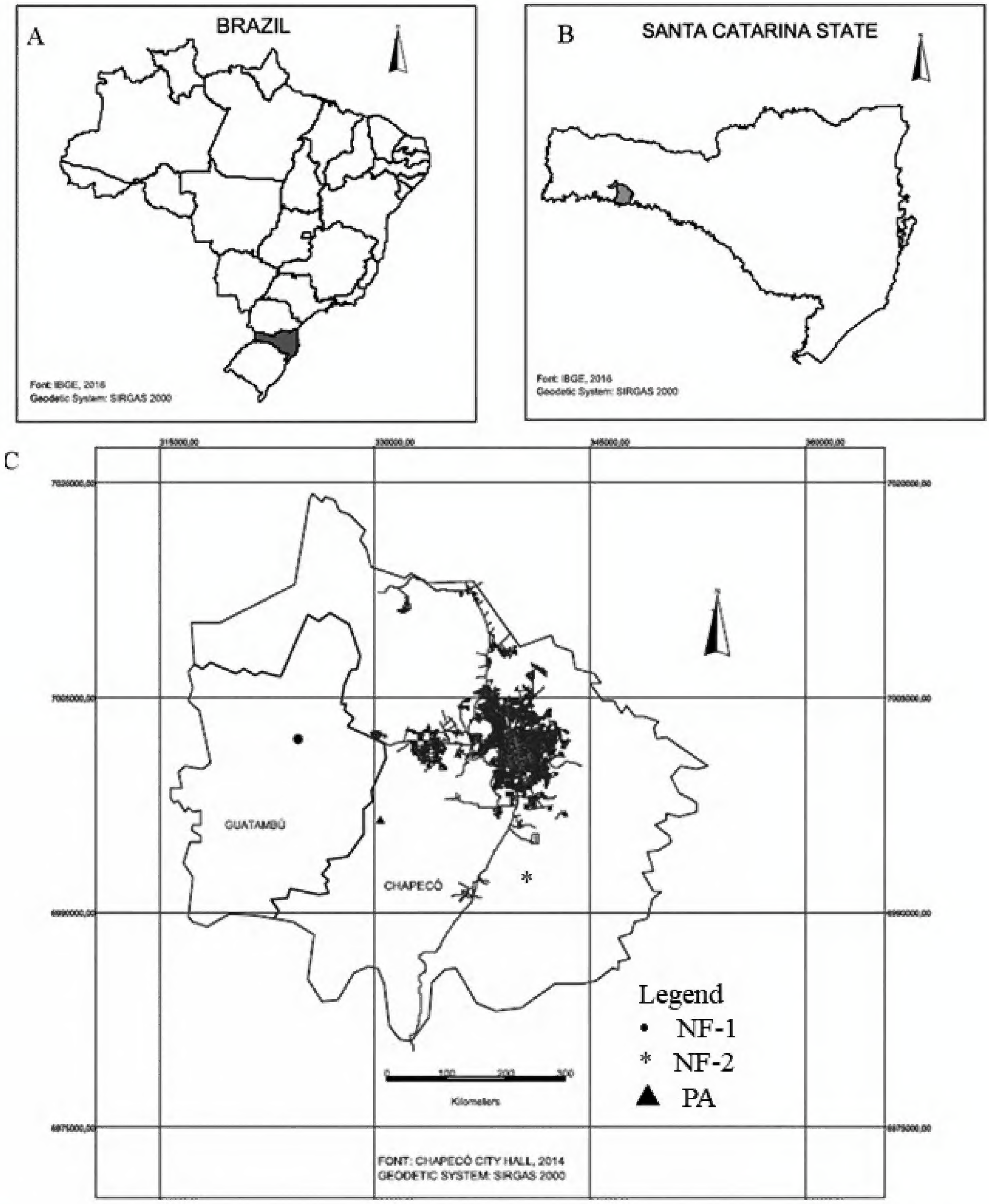

Figure 1. Map showing locations of the three forest remnants of Atlantic Forest (PA, NF-1 and NF-2), where duet vocalizations of *Myiothlypis leucoblephara* were recorded, in southern Brazil. A: In black, location of the state of Santa Catarina; B: In black, identification of the municipality of Chapecó, in the state of Santa Catarina; C: location of the three study areas. Dark line limit of municipalities of Guatambu and Chapecó. Clear lines access routes. NF-1 and NF-2 = fragments in the National Forest of Chapecó; PA = private area.

belong to a Federal Conservation Units and for at least 50 years they are not known to be disturbed. The PA, because it is not officially a Conservation Unit, still suffers anthropic disturbance from the surrounding community. The three fragments are separated by a crop matrix.

Data collection

We recorded vocalizations of different bird pairs (without identification of males and females) both in forest edges and interior of all sites. We considered forest edges to be the portion extending to 250 m within the remnant, and the forest interior as the portion beyond this distance. Recordings on different days at the same location or trail were conducted at least 300 m away from previous recording points (to avoid recording of the same individuals). We go through a transect to make the recordings, being careful to always record different individuals and different places. Whenever a vocalization was recorded, the place was marked from coordinates. It is known that the species is territorial (Aubin et al. 2004), but the size of the used territory is unknown. The recordings were held every fortnight, in the early morning and late afternoon.

A total of 17 duet vocalizations recorded between November 2014 and May 2015 were analyzed and deposited in the laboratory of chemistry and ecology of the Community University of the region of Chapecó (Unochapecó). The first months of the study (November to January) coincide with the reproductive period. Five duets were recorded at the private area site, seven in NF 01, and five in NF 02. Six occurred on the forest edge and 11 in the interior. All recordings were identified by date, time, and location (i.e., site and whether edge or interior). When possible, binoculars (10×42mm) were used for spotting and observing individuals during vocalization. Duets were recorded using a Marantz PMD661 recorder coupled to a directional microphone (Sennheiser K6 Model ME66). Sound recordings were stored as wav-files with a 48 kHz sampling rate and 16 bit data depth.

Data analysis

Song recordings were digitally edited using Audacity 2.1.0; we cut the pieces of the recordings with duet vocalizations for analysis in the Raven Lite 1.0 (Cornell University, Ithaca, NY). We measured the physical variables of vocalizations and divided them into frequency and temporal variables. Frequency variables included maximum and minimum frequency of each phrase in Hz, and maximum and minimum frequency of the first note of each phrase in Hz. Temporal variables included the duration of vocalization for each individual in seconds, the number of notes per phrase, the length of the phrase joining all notes in seconds (Juliano 2010; Nascimento 2012), and the time interval between the 1st and 2nd note of each phrase. A 'note' is an acoustic unit that can be individualized using a sonogram, and a 'phrase' is the set of notes separated by a time interval at least 50% greater than the average interval between notes (Moura 2007). Notes in our recordings were classified according to Silva (1997), as follows: pure, modulated, harmonic acoustic signals, tonal acoustic signals, double voice, trill, and vibrato.

We describe duet phrase emission patterns by examining all existing combinations of different phrases from the 17 duet recordings, which were classified as standards (p). We then described schemes that demonstrate how phrases overlap in different duet patterns.

Statistical analysis

We used a Kruskal-Wallis test with Tukey *post-hoc* comparisons to evaluate differences in minimum and maximum frequency and duet phrase duration (in seconds) among forest sites. We then used a Mann-Whitney *U* test to assess the same variables, as well as the number of notes in a phrase and the average time interval between the first and second note (in seconds) between forest edges and interior. All analyses were performed in SYSTAT 12.0.8.

Results

The phrases of all duets are structured by emission of notes of descending modulation. There are slight frequency changes between notes in different duets in the middle of the phrase (completion notes), when there is alternating low and high frequency of some notes and a sudden drop in frequency in others (Fig. 2), and the characteristic is the same for pairs within a duet, but not the same for different pairs. The acoustic characteristics of the sentences are the same for the two individuals in the duet, but different for different pair of duets.

Vocalizations were more frequent between 7 am and 10 am, and near dusk. As the popular name of the bird suggests, vocalizations occur while the bird hops forward along twigs and branches of the forest understory. *Myiothlypis leucoblephara* vocalization consists of one phrase that initiates with high frequency and noticeably decreases throughout the duration of the song (Fig. 2. The general classification of the notes emitted in the phrase for all individuals was acute tone with pure acoustic signals (only with a frequency) and downward modulation. The call consists of a single note. We found differences in the number of notes, timing and frequency of phrases of duets between different bird pairs.

The total number of notes in the phrases ranged from 13 to 32, and full phrase duration ranged from 3.074 to 8.325 seconds (mean = 5.243, SD = 1.396). The minimum frequency ranged between 2.566 to 5.037 Hz (mean = 3.397, SD = 609.7) while maximum frequency between 7.318 and 10.075 Hz (mean = 8.803 SD = 854.7) (Suppl. material 1). The minimum frequency of the first note in the phrase ranged from 5.037 to 7.603 Hz (mean = 6.399, SD = 668.9) while the maximum ranged from 7.508 to 9.694 Hz (mean = 8.747, SD = 673.5). The minimum time between the first and second note of the phrase was 0.209 seconds, and the maximum time was 1.550 seconds (Suppl. material 2).

Due to the distance of one of the individuals in a pair, in seven recordings (41.2%) some of the initial, high frequency notes were faded or even imperceptible on the spectrogram. This (notes faded or imperceptible on the spectrogram) was not observed from the middle of the phrase and beyond, as these notes tend to have lower frequency and thus have better clarity on the spectrogram.

Birds from private area site have lower minimum frequencies than NF 01 and NF 02 (KW = 13.572, df = 2, $P < 0.05$). NF 01 and 02 did not differ in minimum

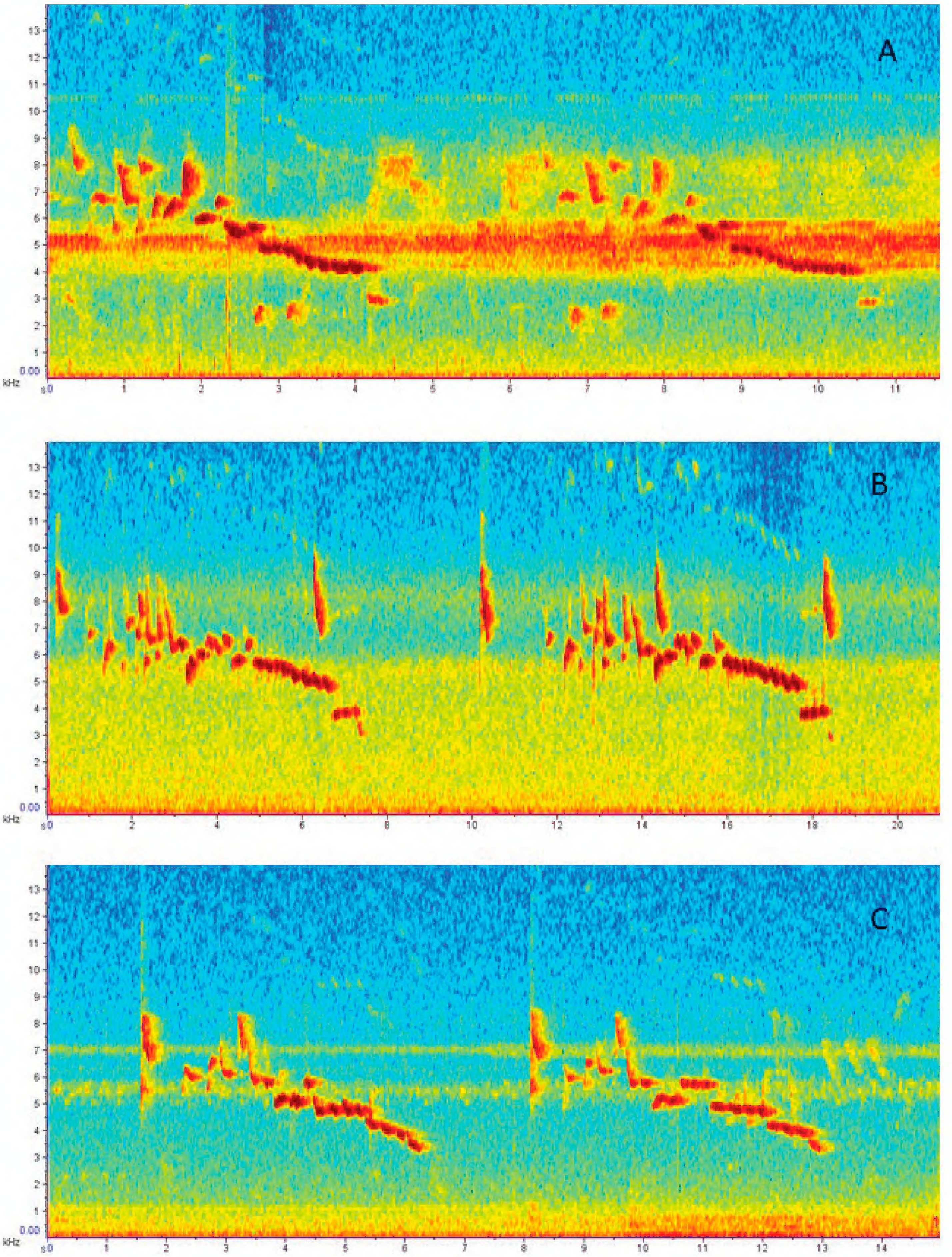

Figure 2. Sonogram of a duet of *M. leucoblephara* registered in PA (A) and NF-1 (B), in southern Brazil. Two individuals appear vocalizing in a duet, one after the other. Sonogram of the complete vocalization sentence of *M. leucoblephara* (C). NF-1 = fragment in the National Forest of Chapecó; PA = private area.

frequency ($P > 0.05$), and there were no differences among the three forest remnants in maximum frequency ($KW = 5.433$, $df = 2$, $P > 0.05$) or phrase duration ($KW = 0.551$, $df = 2$, $P > 0.05$) (Fig. 3).

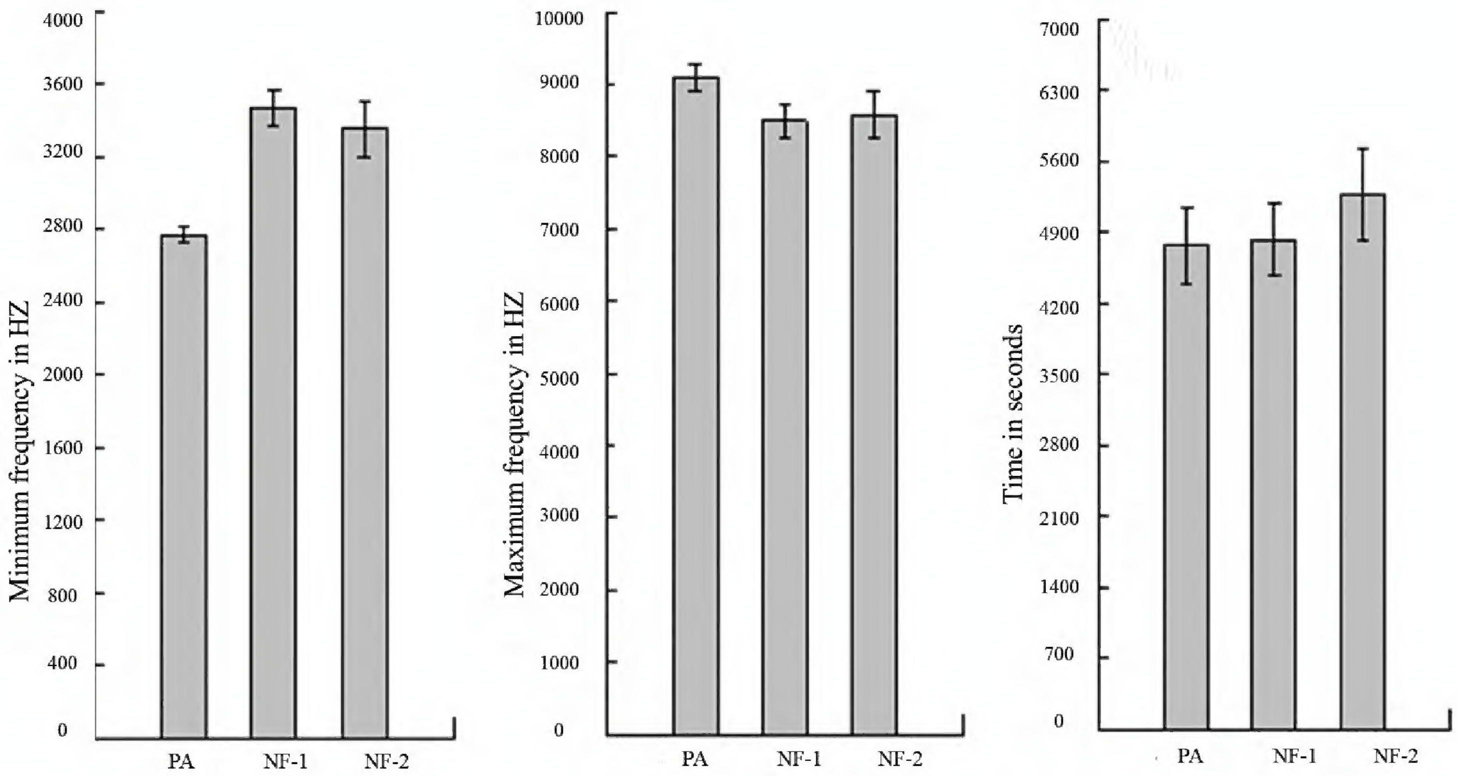

Figure 3. Mean and SD of minimum and maximum frequency (Hz) and phrase duration (s) in *M. leucoblephara* duets between November 2014 and May 2015 in three forest remnants (PA, NF-1 and NF-2) located in southern Brazil. NF-1 and NF-2 = fragments in the National Forest of Chapecó; PA = private area.

There were no differences in phrase minimum (U = 81.000, df = 1, P > 0.05), maximum frequency (U = 72.500, df = 1, P > 0.05), phrase duration (U = 77.000, df = 1, P > 0.05) or number of notes per phrase (U = 60.000, df = 1, P > 0.05) between duets on the forest edge vs. the interior. The forest edge and interior did not differ in minimum frequency of the first note of each phrase (U = 44.500, df = 1, P > 0.05) nor the time (s) between the first and second note of each phrase (U = 44.500, df = 1, P > 0.05). The maximum frequency of the first note of each phrase was marginally higher in the forest interior (U = 21.000, df = 1, P = 0.049).

We discovered five different patterns of overlapping phrases in duets, with one pair demonstrating two vocalization patterns and the other pairs showing only one pattern (Fig. 4). We call the first patterns 'p1', which was present in 12 different duets (70.5%). In this pattern the first individual starts and ends the phrase, then the other individual vocalizes. We call the second pattern 'p2', which was recorded in two different duets (11.7%). Other vocalization patterns were recorded only once. Pattern 1 (p1): one individual vocalizes after the other, with no overlapping phrases or notes between the pair. In this pattern no time elapses between emission of phrases by the first individual and the reply from the other individual.

Pattern 2 (p2): the first individual emits introductory notes, and prior to final notes, individual 2 begins a phrase and they vocalize synchronously for a period of time. In this period individual 1 emits final notes while individual 2 emits introductory notes, then emits final notes alone.

Pattern 3 (p3): the pair vocalizes synchronously.

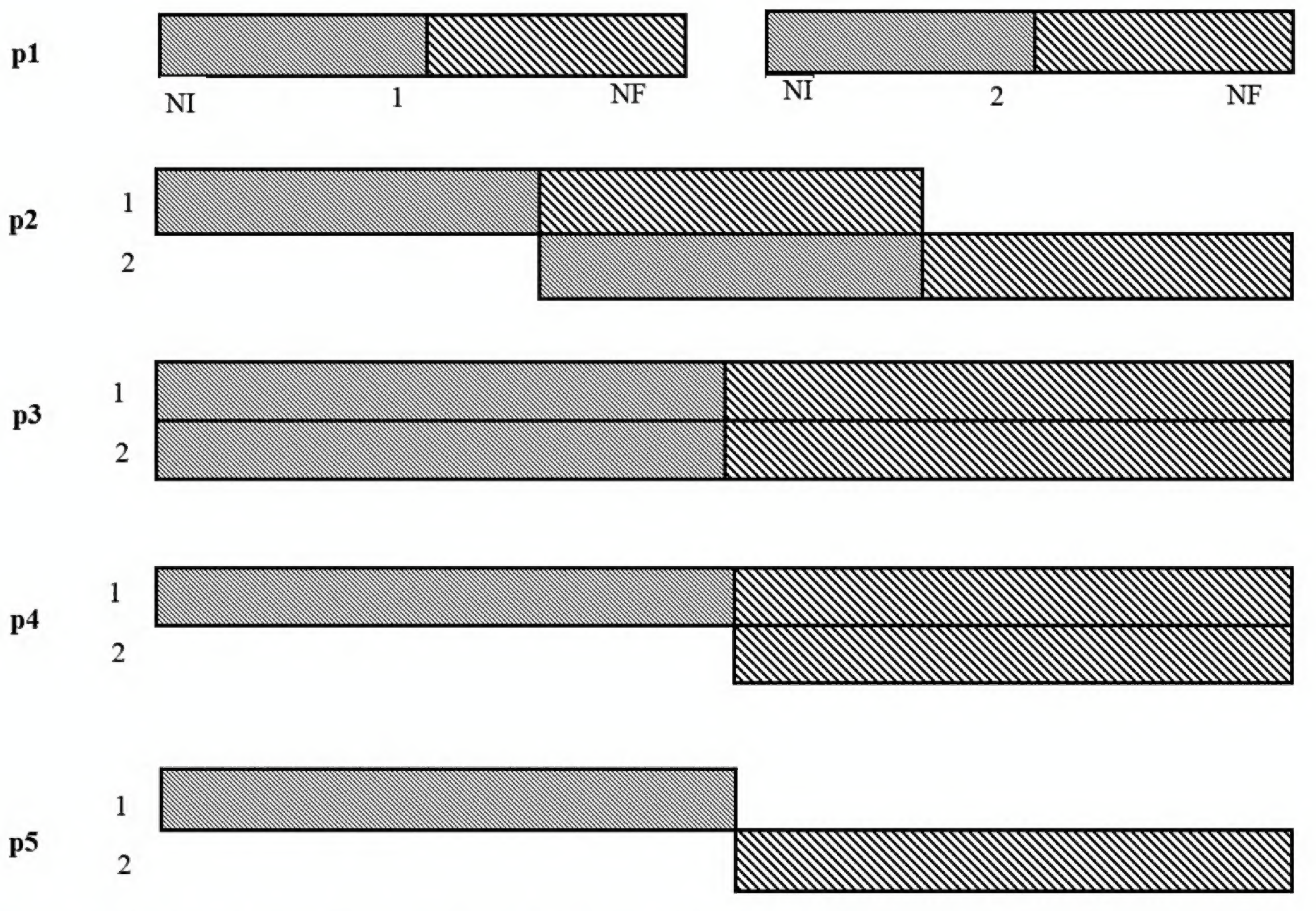

Figure 4. General vocalization patterns. NI = introductory notes (rectangles with finer lines); NF = final notes (rectangle thicker lines); 1 = individual 1; 2 = individual 2; p1, p2, p3, p4 and p5 = patterns 1, 2, 3, 4, and 5, respectively.

Pattern 4 (p4): individual 1 emits the whole phrase, but in the final part of the phrase (final notes) individual 2 begins a phrase consisting only of introductory notes and stopping shortly thereafter. The pair ends the phrase together, sometimes emitting different portions. Pattern 5 (p5): individual 1 begins introductory notes and the other individual emits the final notes. Thus, each individual contributes by vocalizing one part of the duet.

The only pattern recorded in all three remnants (PA, NF 01 and 02) and in both forest areas (edge and interior) was pattern 1. Pattern 2 was recorded only in NF 01, both in the forest interior and edge. Pattern 3 was recorded only in the interior of NF 01. Pattern 4 was only recorded in PA, and pattern 5 was recorded in the forest interior of NF 01. NF 02 was the only remnant with no recordings with phrase overlapping in duets.

Discussion

The differences between *M. leucoblephara* pairs among forest remnants in duet characteristics, such as note frequency range and number of notes per phrase, are likely indicators of family group recognition. These birds have the sensitivity to recognize

vocal alterations in notes, increase in the number of notes, and frequency variations, which they use to identify partners, family members, and invaders in their territory (Carvalho 2010). The various functions of avian duet vocalization are diverse and subject to controversy, but may also involve individual recognition (Vielliard 1987).

Individual recognition is generally associated with species that have similar vocalizations as in *M. leucoblephara*, suggesting that species with individual vocal repertoires are sensitive to subtle differences in vocalization (Aubin et al. 2004). Vocalization structure can be diverse. Acoustic elements can be shared but issued differently; different acoustic elements may be emitted in sequence, or imitation may occur without a defined sequence. These categories are not found in isolation, as individuals from the same species may fit into different categories (Vielliard 2004).

Volatinia jacarina (blue-black-grassquit) (Thraupidade, Passeriformes) and *M. leucoblephara* showed a huge inter-individual variation in the physical structure of vocalization. Individuals can accurately repeat extremely complex details of a song which lasts around half a second, but identical structures are not found among different individuals (Vielliard 2004). Five *Turdus* species (Turdidae, Passeriformes) show significant overall differences between individuals in both the temporal and frequency variables of vocalizations (Nascimento 2012). Troglodytidae and Turdidae have a minimum number of within-species differences in vocalization patterns and individual recognition information is thus reduced to characteristics of note rhythm or harmonic structure, demonstrating intra-individual versatility (Vielliard 1987). *Oryzoborus angolensis* (chestnut-bellied seed-finch) also showed significant inter-individual differences in note duration, time interval between notes, notes per second, and minimum and maximum frequency (Lopes 2011). The results from this study reinforce the concept that each species or individual uses different vocal recognition characteristics. The vocal characteristics of *M. leucoblephara* are shared between duet partners (i.e., with respect to the emission of phrases) and pairs can accurately mimic vocalization structure. One study of isolated individuals in captivity discovered potential clues about the identity of the individual signature in the first half of the phrase (Aubin et al. 2004). In our study we found small differences at the beginning of the phrase, but the main differences between units were found in the second half of the sentence.

Individual acoustic recognition was first discovered in the Laridae family, a seabird group that nests in dense colonies and cannot use visual location signals. They instead use harmonic variation in vocalization to identify partners, or to distinguish individuals within organized societies (i.e., as in *Cacicus* spp.) (Vielliard 1987). Penguins also perform duets for individual recognition when searching for partners among the multitude of individuals gathered during the incubation period (Vielliard 1987). Individual recognition is a prerequisite for social interactions, including parental care and cooperation between breeding pairs (Stoddard 1996).

Habitat loss in a steppe matrix markedly affected song-type sharing mechanisms in *Chersophilus duponti* (Dupont's lark). In fragmented habitats, song sharing among neighbors was better, possibly because of harsher competition for limited resources, whereas sharing among non-neighbors was lower, probably because of

the lack of interactions among individuals isolated by habitat barriers. Local habitat fragmentation may alter behavioral processes by hampering the local transmission of song cultures, in particular the spatial range of individual acoustic niche contracts at increasing fragmentation levels (Laiolo and Tella 2005). The PA, which differed from the others, is a smaller area and is not a protected area; it still suffers anthropic disturbance from the surrounding community.

Small variations in phrase timing and frequency among some duets are considered irrelevant, as birds are rarely able to vocalize with the exact same frequency and time variables as the other individual (Lima 1997). Moreover, the degree in precision of mimicking vocal characteristics can be influenced by environmental factors such as rain and wind, and at times equipment errors may limit the ability to accurately assess (Lima 1997).

Myiothlypis leucoblephara duet performance may be associated with territorial defense or food resource. Several tropical birds vocalize in duets throughout the year to defend territories (Langmore 1998). This territoriality is considered a selection strategy, wherein an animal yields possession of a location, food resource, or partner because another individual arrived first (Rose 2000).

Although the acoustic structure of *M. leucoblephara* is simple, there are propagation problems associated with the restrictive environment of a tropical forest and there is a need to transmit efficient information (common in species with specific recognition), the vocalization of the species satisfies an important requirement of territoriality: the identification between neighbors (Aubin et al. 2004). Analysis of duets revealed that each pair has unique characteristics regarding the issue of notes within phrases, which makes other individuals or intruders easily recognizable.

Most duet recordings had some missing or imperceptible notes in the spectrogram, always those with highest frequency in every phrase. Higher frequencies have more rapid attenuation than do low frequency in environments with obstacles such as branches, leaves, or air turbulence or viscosity (Krebs and Davies 1996). Experiments by Aubin et al. (2004) with the same species showed that beyond a distance of 100 m, the first notes are absent in some individuals, and hence, the vocal signature disappears in the background noise. According to the authors, short-range propagation of vocal information seems to be an adaption of territorial species, which serves to reduce aggressive responses to unknown birds and, hence, limit unwarranted energy consumption for territorial defense.

Morton (1975) showed that birds near the ground would be able to transmit acoustic signals further in the frequency range of 1000–2500 Hz, and that attenuation is increased above 2,000 Hz. Our study does not support this assessment, as *M. leucoblephara* lives in the understory and had minimum and maximum vocalization frequency between 2,566 and 10,075 Hz, respectively. Maybe the species has no need to communicate across long distances.

Myiothlypis leucoblephara showed no significant differences in vocalization structure between the forest edge and interior. A study by Silva (1991) concluded that this species does not show significant differences, suggesting that vo-

calization is adapted to a particular environment. These results contradict those found by other authors for most species. The structure of bird vocalization is closely related to the habitat in which they live, and this can be seen at the scale of forest edge, interior, or opening (Morton 1975; Storer et al. 2002). Habitats differ with respect to density and vegetation type, resulting in different selection pressures on acoustic signals, as a consequence of the way the sound is attenuated and degraded as it penetrates the physical environment (Slabbekoorn and Smith 2002). Environmental factors may select for specific vocalization characteristics, sometimes causing acoustic convergence among populations living in the same habitat and divergence among populations living in different habitats (Aubin et al. 2004). Other species in the Parulidae family, such as *Myiothlypis flaveola* (flavescent-warbler) and *Myiothlypis leucophrys* (white-striped-warbler), showed significant differences in maximum and minimum frequency, number of notes, and duration of vocalization between populations in urban vs. rural fragments (Carvalho 2010). *Myiothlypis fulvicauda* (buff-rumped-warbler) vocalizations differed based on environment and geographical variation (Escalante 2013).

Environmental and social factors are not enough to explain the diversity of bird vocalizations, because closely related species groups often have vocalizations with similar acoustic properties. Regardless, some vocalization characteristics evolve in response to the selection, while others remain similar. This may occur because vocalization characteristics are neutral with respect to the physical environment, or because evolutionary change is limited by genetic correlations or lack of variance (Van Buskirk 1997).

The birds can recognize neighbors or intruders in their territory through the detection of simple variations in vocal repertoire. *Myiothlypis leucoblephara* showed no significant differences in structural characteristics, minimum or maximum frequency, number of notes per phrase, or time of phrase execution between forest edge and interior environments. The vocalization of a species has a characteristic of its own (Silva 1991), not being modified by the type of habitat that lives.

Myiothlypis leucoblephara did not show species-specific duet patterns, instead presenting several emission patterns and overlapping phrases in the duets. Duet vocalization occurs when two individuals vocalize in combination with one another or in an alternating synchronized manner (Langmore 1998). The participation of each individual in the duet and organization of it are variable for each species or different individuals (Vielliard 1987). The duet may consist of verses that last for the same period of time but are not linked together; also one individual can vocalize after the other and the verses may be the same or different (Sick 1997).

Further studies should be carried out on duets of other species to evaluate syntax modification, phrase modulation, and dispersion of pairs or family members to assess the territory covered by groups. Playback experiments may also be useful to test the extent of individual recognition, as well as phylogenetic studies of vocalization in *M. leucoblephara* and other species of *Myiothlypis*.

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References

Aubin T, Mathevon N, Silva ML, Vielliard JME, Frederic S (2004) How a simple and stereotyped acoustic signal transmits individual information: The song of the White-browed Warbler *Basileuterus leucoblepharum*. Anais da Academia Brasileira de Ciências 76(2): 335–344. https://doi.org/10.1590/S0001-37652004000200022

Carvalho LSD (2010) Repertório vocal e variações no canto de *Basileuterus* spp. (Passeriformes, Parulidae) em fragmentos de mata (Uberlândia MG). Dissertação, Uberlândia, Brasil: Universidade Federal de Uberlândia (UFU).

Develey PF (2004) Guia de campo: aves da grande São Paulo. 1ª Ed. Editora Ltda, São Paulo, 295 pp.

Escalante I (2013) Comportamiento de canto, descripción de las vocalizaciones y su posible variación geográfica en Costa Rica en *Myiothlypis fulvicauda* (Parulidae: Aves). Zeledonia 17(1): 36–53.

ICMBIO (2013) Plano de manejo da Floresta Nacional de Chapecó – Resumo executivo. Instituto Chico Mendes de Conservação da Biodiversidade. Florianópolis – SC. [s.n], 49 pp.

Juliano RF (2010) Influência da massa corporal, da filogenia e do habitat sobre a estrutura da vocalização de aves brasileiras. Dissertação, Uberlândia, Brasil: Universidade Federal de Uberlândia (UFU).

Krebs JR, Davies NB (1996) Introdução à ecologia comportamental. Tradução Ramalho, Mauro; Machado, Cíntea Pinheiro. Ateneu Editora, São Paulo, 420 pp.

Laiolo P, Tella JL (2005) Habitat fragmentation affects culture transmission: Patterns of song matching in Dupont's lark. Journal of Applied Ecology 42(6): 1183–1193. https://doi.org/10.1111/j.1365-2664.2005.01093.x

Langmore NE (1998) Functions of duet and solo songs of female birds. Trends in Ecology & Evolution 13(4): 136–140. https://doi.org/10.1016/S0169-5347(97)01241-X

Lima VS (1997) Os sons do Pitiguari *Cyclarhis gujanensis*. Dissertação, Campinas, Brasil: Universidade de Campinas - UNICAMP.

Lopes JP (2011) Análise da comunicação sonora do Curió *Oryzoborus angolensis* (Aves, Passeriformes, Emberizidae). Dissertação, Belém, Brasil: Universidade Federal do Pará (UFPA).

Morton ES (1975) Ecological Sources of Selection on Avian Sounds. American Naturalist 109(965): 17–34. https://doi.org/10.1086/282971

Moura LN (2007) Comportamento do Papagaio-do-mangue *Amazona amazonica*: gregarismo, ciclos nictemerais e comunicação sonora. Dissertação, Belém, Brasil: Núcleo de Teoria e Pesquisa do comportamento, Universidade Federal do Pará (UFPA).

Nascimento LFT (2012) Estrutura e organização de sistemas complexos de comportamento vocal em cinco espécies do Gênero *Turdus* (Aves, Passeriformes, Turdinae). Dissertação, Belém, Brasil: Universidade Federal do Pará (UFPA).

Pereira SMF (2011) A influência da bioacústica na evolução da ciência em Portugal: interface da bioacústica e monitorização da biodiversidade. Dissertação, Lisboa, Espanha: Universidade Técnica de Lisboa.

Pijanowski BC, Villanueva-Rivera LJ, Dumyahn SL, Farina A, Krause BL, Napoletano BM, Gage SH, Pieretti N (2011) Soundscape Ecology: The Science of Sound in the Landscape. Bioscience 61(3): 203–216. https://doi.org/10.1525/bio.2011.61.3.6

Rose M (2000) O espectro de Darwin: a teoria da evolução e suas implicações no mundo moderno. 1ª ed. Editora Jorge Zahar, Rio de Janeiro, 268 pp.

Salvador CC (2008) A bioacústica aplicada à comunicação humana – revisão da literatura e tendências. Monografia, Rondônia, Brasil. Departamento de Ciências Exatas e da Natureza, Universidade Federal de Rondônia (UFR).

Sick H (1997) Ornitologia brasileira. 3ª impressão. Ed. Nova Fronteira, Rio de Janeiro, 912 pp.

Sigrist T (2006) Aves do Brasil: uma visão artística. 2ª ed. Editora Avis Brasilis, São Paulo, 672 pp.

Silva WR (1991) Padrões ecológicos, bioacústicos, biogeográficos e filogenéticos no complexo *Basileuterus culicivorus* (Aves, Parulidae) e demais espécies brasileiras do gênero. Tese de Doutorado. Universidade Estadual de Campinas, Unicamp. Campinas, SP.

Silva ML (1995) Estereotipia e versatilidade nos cantos das aves: Os padrões de canto em sabiás e outras aves. Anais de Etologia 13: 133–147.

Silva ML (1997) Descrição do repertório vocal do Sabiá-laranjeira *Turdus rufiventris* (Aves, Passeriformes, Turdinae). Dissertação, São Paulo, Brasil: Universidade de São Paulo.

Silva ML, Vielliard JME (2011) A aprendizagem vocal em aves: evidências comportamentais e neurobiológicas. In: Henriques AL, Assis GJA, Brito RCS, Martin WLB (Orgs) Estudos do comportamento II. Editora da UFPA, Belém, 182 pp.

Slabbekoorn H, Smith TB (2002) Bird song, ecology and speciation. The Royal society 357: 493–503. https://doi.org/10.1098/rstb.2001.1056

Stoddard PK (1996) Vocal recognition of neighbors by territorial passerines. In: Kroodsma DE, Miller EH (Eds) Ecology and Evolution of Acoustic Communication in Birds. Cornell University Press, Ithaca, NY, 356–374.

Storer TL, Usinger RL, Sterbbins RC, Nybakken JW (2002) Zoologia geral. Tradução Erika Schlenz. Companhia editor nacional. 6ª ed. São Paulo – SP, 816 pp.

Topp SM, Mennill DJ (2008) Seasonal variation in the duetting behaviour of rufousand-white wrens (*Thryothorus rufalbus*). Behavioral Ecology and Sociobiology 62(7): 1107–1117. https://doi.org/10.1007/s00265-007-0538-4

Van Buskirk J (1997) Independent evolution of song structure and note structure in American Wood-warblers. Proceedings of the Royal Society of London: Biological Science 264(1382): 755–761. https://doi.org/10.1098/rspb.1997.0107

Vielliard JME (1987) Uso da bioacústica na observação de aves. In: Coelho EP (Ed.) II II Encontro Nacional de Anilhadores de Aves. UFRJ, Rio de Janeiro, 98–121.

Vielliard JME (2000) Estado atual das pesquisas em bioacústica e sua contribuição para o estudo e a proteção das aves no Brasil. In: Alves MAS, Cardoso JMC, Van Sluys M,

Bergallo HG, Rocha CFD (Orgs) A Ornitologia no Brasil: pesquisa atual e perspectivas. UERJ, Rio de Janeiro, 287–301.
Vielliard JME (2004) A diversidade de sinais e sistemas de comunicação sonora na fauna brasileira. Anais do I Seminário Música Ciência e Tecnologia, São Paulo 1(1):145–52.

Supplementary material 1

Maximum and minimum frequency of the first note in the phrase, and time elapsed between first and second notes in *M. leucoblephara* duets recorded in three forest remnants of Atlantic Forest, in southern Brazil.

Authors: Marciela Batistela, Eliara Solange Müller

Data type: species data

Explanation note: NF-1 and NF-2 = fragments of the National Forest of Chapecó; PA = private area. The numbers 1 and 2 serve to differentiate the vocalization of the two individuals who vocalize in a duet. -: indicates deleted or absent data, or data points for which we were unable to assess accurately variables.

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Supplementary material 2

Minimum (Min Freq (Hz)) and maximum (Max Freq (Hz)) frequency, phrase duration (Time (s)), and number of notes emitted by *M. leucoblephara* duets in three forest remnants of Atlantic Forest, in southern Brazil

Authors: Marciela Batistela, Eliara Solange Müller

Data type: species data

Explanation note: NF-1 and NF-2 = fragments of the National Forest of Chapecó; PA = private area. The numbers 1 and 2 serve to differentiate the vocalization of the two individuals who vocalize in a duet.

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